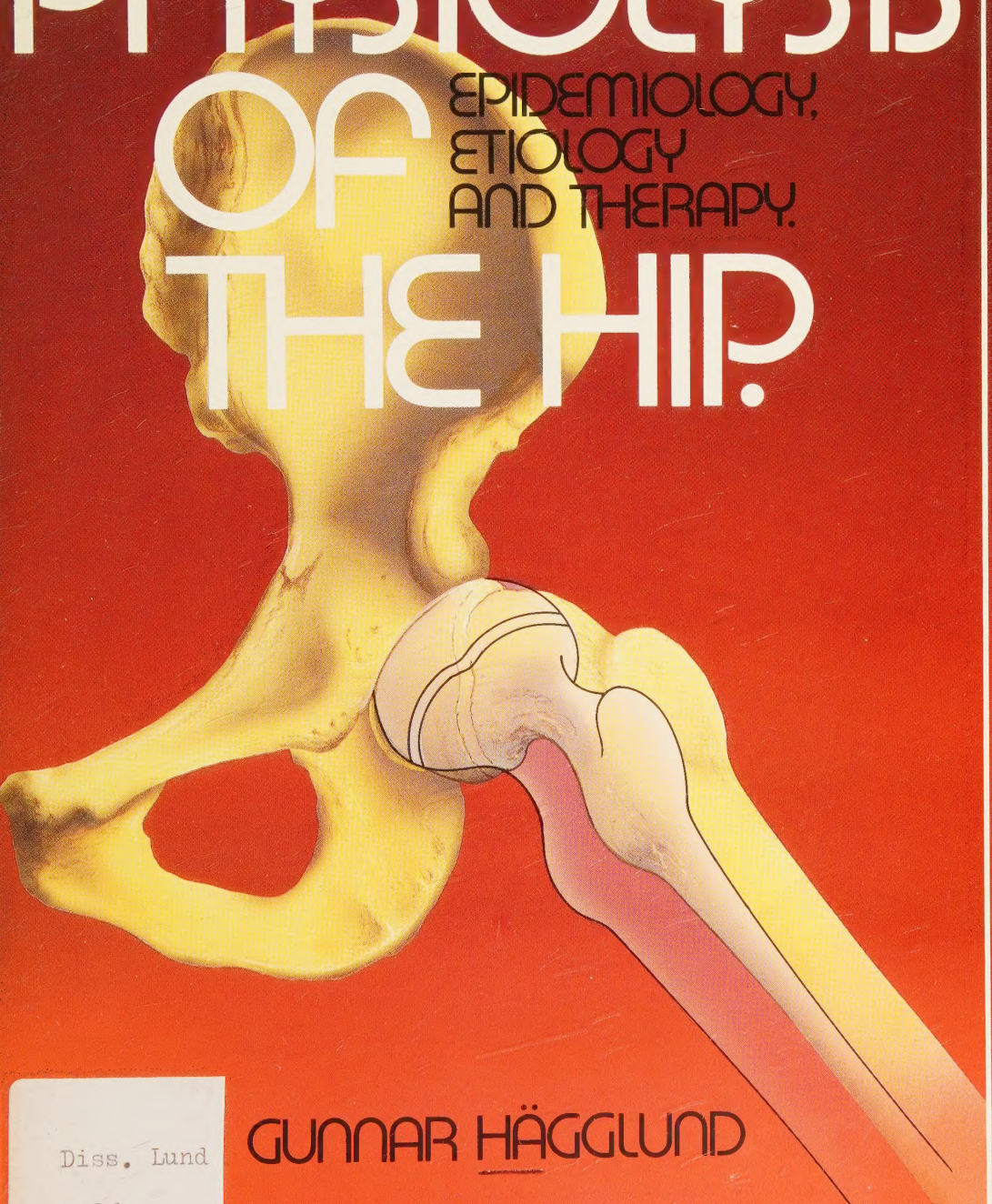


PHYSIOLOGY OF THE HIP

EPIDEMIOLOGY,
ETIOLOGY
AND THERAPY.

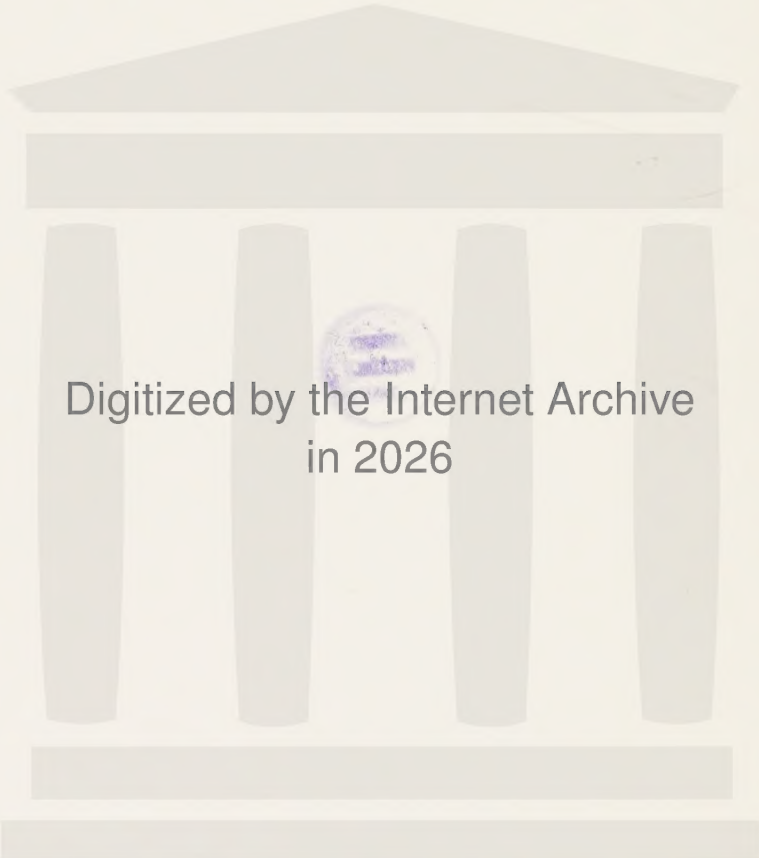


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Title and subtitle PHYSIOLOGY OF THE HIP Epidemiology, etiology and therapy		
532 cases of slipped capital femoral epiphysis, or physiophys colli femoris (PCF), in southern Sweden from 1910 through 1982 were analyzed epidemiologically. Subsets were used for different investigations aimed at surveying the etiology of PCF, and long-term follow-ups were conducted after operative treatment. A new method to diagnose and grade PCF was developed, using the calcar femorale as a landmark to which the femoral head was related. The method is easy to use and it is able to determine PCF also after growth-plate closure. Epidemiologic analysis of the total material revealed large changes during the 20th century. The male predominance has decreased from 90% to 60%. Mean age at slipping has decreased by about 3 years in males and by about 1 year in females. The incidence has followed a periodic pattern with peaks every 20th year. The mean incidence was 6/10,000 in boys and 3/10,000 in girls. The etiologic investigations dealt with hereditary, mechanical, and hormonal aspects. Radiographic examination revealed PCF in 10% of the first-degree relatives of 50 consecutive patients with PCF. Growth analysis showed in both sexes an above average body height before puberty, but a lower than normal pubertal gain in height. Both the boys and the girls were markedly overweight before puberty and remained so at maturity. Roentgenstereophotogrammetric analysis of longitudinal growth in the distal fibula showed in both sexes a normal rate during the years after pinning of the PCF. However, at diagnosis 17 children of the 32 investigated had a body height exceeding the mean by more than 1 SD, indicating higher than average growth rate before diagnosis. In the investigations concerning therapy, 33 cases treated by femoral neck osteotomy and 172 cases treated by Johansson nailing or Nyström pinning were evaluated on average 28 (16-42) years after surgery. Of the osteotomized patients 1/3 sustained segmental collapse and/or chondrolysis. These patients developed severe arthrosis at an early age and had a poor function at follow-up. Of the nailed/pinned cases, 4 of 25 hips treated with reduction and 4 of 179 hips operated on without reduction developed segmental collapse and poor long-term results. Arthrosis was twice as frequent at follow-up after reduction than after fixation in situ. It is concluded that pinning in situ is the method of choice regardless of degree of slipping. Bilateral slipping was found in 62% of the patients at follow-up, indicating prophylactic pinning of the contralateral hip.		
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PHYSIOLOGY OF THE HIP

Epidemiology, etiology and therapy

av

Gunnar Hägglund

Leg läk

Lunds nation

AKADEMISK AVHANDLING

som med vederbörligt tillstånd av Medicinska Fakulteten i Lund för avläggande av medicine doktorsexamen kommer att offentligen försvaras i Föreläsningssal 3, Centralblocket, Lasarettet i Lund, fredagen den 7 november 1986 kl 14.00.

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Umeå

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Göteborg

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From the University Department of Orthopedics in Lund, Sweden

PHYSIOLOGY OF THE HIP. EPIDEMIOLOGY, ETIOLOGY AND THERAPY.

GUNNAR HÄGGLUND

1986

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Abbreviations

ATD	Articulotrochanteric distance
ICP	Infancy, childhood, puberty
M	Mean
PCF	Physiolysis colli femoris
PHV	Peak height velocity
RSA	Roentgen stereophotogrammetric analysis
SD	Standard deviation
SDS	Standard deviation score

I Introduction

Slipped capital femoral epiphysis, or epiphysiolysis capitis femoris, was first described by Paré in 1572: "...l'épiphyse de la tête de cet os quelquefois se separe et disjoint, de sorte que le Chirurgien est déçu, estimant qu'il y ait luxation et non disjonction de l'épiphyse dudit os." The slip occurs through the physis of the femoral neck, not through the growth cartilage of the bony epiphysis. Consequently, in what follows, the denomination physiolysis colli femoris (PCF) will be used.

Until the end of the 19th century, PCF was only sporadically reported and was then associated with trauma. With the advent of radiography it could be demonstrated that trauma was not the only cause of PCF. During the 20th century, further efforts have been made to determine the etiology of PCF and to improve its treatment. However, the etiology of PCF is still unknown, despite the fact that several predisposing factors have been identified, and there is still no consensus as regards treatment.

Sometimes there are difficulties in detecting PCF and determining the degree of slipping. Earlier presented methods (Billing 1954, Bianco 1966, Griffith 1976, Engelhardt 1984) are useful in cases with an open growth plate of the femoral neck. Satisfactory techniques for analyzing the deformity in adults are lacking.

Epidemiologic studies have revealed racial, geographical, and sex differences in the incidence of PCF (Kelsey et al. 1970, Ninomiya 1976). Kelsey et al. (1970) made an excellent epidemiologic investigation in New Mexico and Connecticut. However, the population and catchment areas

could not be clearly defined and the incidence values are difficult to compare with other calculations of incidence.

From case reports and investigations based on interviews and clinical reports, a hereditary predisposing factor has been pointed out (Wilson et al. 1965, Rennie 1982). Because many slippings are asymptomatic (Jerre 1950), the true frequency of PCF among relatives is, however, not known.

Animal experiments (Harris 1950, Morscher 1968) and case reports on PCF associated with hormonal disorders (Heyerman & Weiner 1971, Primiano & Hughston 1971, Puri et al. 1985) indicate that hormonal disturbances affect the strength of the physis. It is also known from animal experiments that the growth plate is weaker at puberty and at time of rapid growth (Morscher 1968). Additionally, several investigations have shown that these children have an abnormal body constitution at the time of diagnosis (Bianco 1965, Kelsey 1972). However, longitudinal analysis of growth in PCF children before, during, and after slipping is lacking.

The most serious early complications of PCF are osteonecrosis, first described by Axhauser in 1922, and chondrolysis, first described by Waldenström in 1930, whereas the most serious late complication is arthrosis, which is often not seen until middle life.

The recommendations of treatment vary mostly with the degree of slipping. In mild PCF, most authors recommend pinning in situ (Wiberg 1959, Bianco 1965, Hansson 1982) or bone pegging physiodesis (Howorth 1966). In severe PCF, most authors recommend a realignment procedure: osteotomy through the physis or midneck region (Klein et al. 1948, Dunn 1975, Nelson 1980, Fish 1984), through the base of the femoral neck (Kramer et al. 1976, Gage et al. 1978), or at the trochanteric/subtrochanteric region (De Palma et al. 1964, Southwick 1967). Most arguments are based on short-term follow-ups, only concerning the early complications. However, because arthrosis is not seen until middle life, long-term follow-ups are also required, when the different methods of treatment are evaluated.

At the Department of Orthopedics in Lund, much interest has been given to PCF. Frising (1926) investigated 32 cases with coxa vara and concluded that PCF can occur without trauma and only secondarily gives rise to coxa vara. Jerre (1950), in his thesis, analyzed 166 cases of PCF in southern Sweden between 1917 and 1945 and found superior results in nontreated cases when compared with those treated with closed reduction. Wiberg (1959, 1966) analyzed the short-term results after nailing/pinning and femoral neck osteotomy. In 1982, Hansson reported the short-term results after fixation with the hook-pin. Finally Ordeberg (1986) investigated the natural history of PCF, with a follow-up time of 20-60 years.

The aim of this study was as follows:

1. To develop a radiographic method that is able to determine PCF also after growth-plate closure.
2. To analyze the incidence and epidemiology of PCF in southern Sweden during this century.
3. To evaluate the heredity of PCF using radiographic examinations.
4. To evaluate the longitudinal growth pattern (a) using roentgen stereophotogrammetric analysis (RSA), which, with very high accuracy, reveals small growth rate aberrations, and (b) using the Karlberg (1986) ICP (Infancy, Childhood, Puberty) growth model, which is in agreement with what is known about hormonal regulation of growth.
5. To evaluate the long-term results after nailing or pinning and after femoral neck osteotomy.

II Patients

A total of 532 children with PCF diagnosed or treated at three orthopedic departments in southern Sweden (Lund University Hospital, Malmö General Hospital, and Helsingborg Orthopedic Hospital) between 1910 and 1982 were collected from case record registers and operating room log books. Only cases with PCF that were diagnosed radiographically during adolescence were included.

The material was used totally and in subsets in the different investigations as presented in Table 1.

Table 1. Number of PCF cases in the different investigations

	PCF-cases	Comments
1. Epidemiology	532	Total material
Incidence analysis	325	Those living in the primary catchment area (Malmöhus County)
2. Radiographic method	56	Normal material 80 hips, control sample another 50 hips.
3. Heredity	50	Consecutive cases.
4. Body weight and height	40	From primary sample of 52 consecutive cases
5. Longitudinal bone growth	32	Primary operation 1977-1982
6. Nailing/pinning	172	Operated on 28 (20-42) years before reexamination; Nailing 32 (21-42) years, pinning 25 (20-38 years).
7. Femoral neck osteotomy	33	Operated on 28 (16-32) years before reexamination.

III Methods

A. RADIOGRAPHY

In order to develop a method that is able to detect PCF and determine the degree of slipping also after growth-plate closure, the anatomic structure calcar femorale (Harty 1957) was analyzed and used as a landmark (Hansson et al. 1986).

First, the course of the calcar femorale was investigated radiographically in 12 anatomic specimens. Secondly, on radiographs of 80 normal hips (18 males, 22 females; 9-37 years), the calcar femorale was identified on Lauenstein projections and related to the central axis drawn through the center of the femoral head perpendicular to the growth plate or the scar from the growth plate (Figure 1). On an additional 50 normal hips (25 male, 25 female; 10-35 years), the same measurements were made, determining the reliability of the first normal sample. Thirdly, in 34 boys

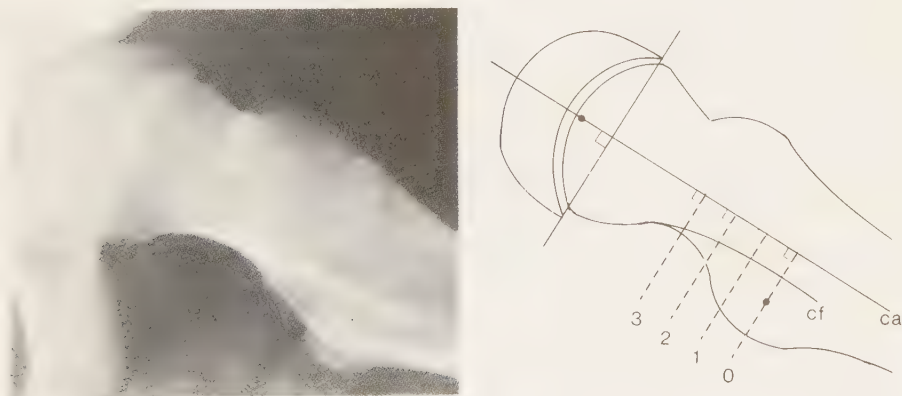


Figure 1. Relation between calcar femorale (cf) and central axis (ca) in a normal hip. Levels of measurement and center of the femoral head and the lesser trochanter indicated.

and 22 girls with PCF, the degree of slipping was determined using the relation between the calcar femorale and the central axis obtained in the normal material.

B. EPIDEMIOLOGY

In each case the sex, place of residence, side of slipping, age at onset of symptoms, time of the year at onset of symptoms, and delay between onset and diagnosis were recorded (Hägglund et al. 1984). The incidence calculations of the patient material from the primary catchment area were possible because of the national registration of the population.

C. HEREDITY

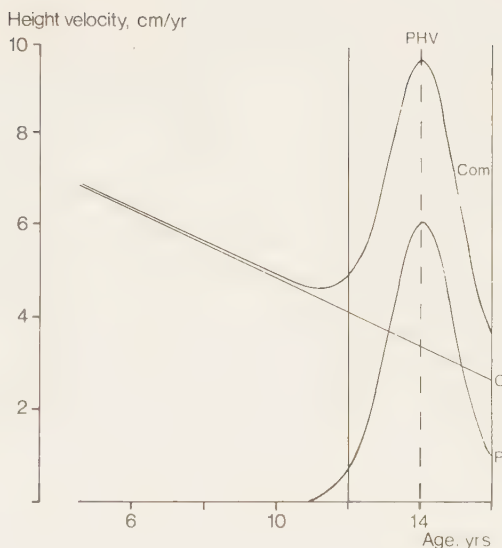
The first-degree relatives (e.g., parents, brothers and sisters) above the age of adolescence were examined radiographically (Hägglund et al. 1986b). Anteroposterior and Lauenstein projections were used; and, besides a standard examination, the femoral head/calcar femorale relationship (Hansson et al. 1986) was determined. The families were interviewed regarding PCF among second degree relatives (e.g., grandparents and consanguineous aunts or uncles).

D. BODY WEIGHT AND HEIGHT

To be included, longitudinal records of body measurements had to be available for the period before the age at onset of slipping to skeletal maturity. These were lacking and lead to exclusion of 12 probands (7 boys, 5 girls) from the primary sample of 52 patients.

Information on attained weight and height during childhood and adolescence was obtained in all patients from their individual school growth charts (Hägglund et al. 1986d). These measurements were generally recorded once a year by school nurses. After the age of pinning the PCF, weight, and height were recorded at annual examinations at the hospital until the age at which subcapital growth-plate closure in both hips took place, which occurred 2-4 years after the individual age at maximum gain during puberty. Final height was recorded at least 3 years after the age of maximum gain. From questionnaires, current parental weight and height were obtained in 33 of the 40 families.

Figure 2. Average height velocity during childhood and adolescence as decomposed by the ICP growth model; mean childhood component (C), mean puberty component (P), and mean combined growth (Com), i.e., the sum of the childhood and puberty components. Reference values during adolescence are adjusted individually by timing the puberty component to the actual age at peak height velocity (PHV) for an individual.



The reference values given in terms of the ICP model take the individual variations in pubertal maturation into consideration by adjusting them to the individual age at maximum growth during puberty (= peak height velocity, PHV). This can be done because the size of the puberty component has been shown to be independent of the time of its occurrence and is superimposed on the decelerating childhood component (Karlberg et al. 1986, Figure 2).

Age at PHV was individually determined by observing the individual velocity curve for height, which had been smoothed by a spline function. Age at PHV could be converted into standard deviation scores (SDS, i.e., deviation from the reference mean expressed in units of standard deviation of the normal population) according to reference values given by Karlberg et al. (1986). Attained height at 2 years before age at PHV, attained height at maturity (final height), and total gain of height during puberty could all be expressed in SDS (Karlberg et al. 1986).

E. LONGITUDINAL BONE GROWTH

One or two tantalum balls (diam. 0.5 mm) were inserted into the distal fibula on each side of the growth plate at the time of hip surgery or within 1 month after surgery (Hägglund et al. 1986e). The bone markers were inserted in both legs (18 cases), on the nonslipped side only (7 cases) or on the slipped side only (7 cases). In one boy, tantalum balls were inserted 14 months before the diagnosis of PCF. Only growth rates after pinning were used for the mean growth calculations.

The patients were followed with repeated roentgen stereophotogrammetric examinations (Selvik 1974, Kärrholm et al. 1982) at intervals averaging 5 (1-29) months. The total observation time averaged 28 (8-61) months.

The growth rate in each case was separated into age groups according to chronologic and skeletal age. Skeletal age was determined on the basis of Greulich & Pyle (1959) on radiographs of the wrist. The mean growth rates in different age groups were calculated for the boys and girls separately and compared with a normal material (Kärrholm et al. 1984). The growth rates during the first and second of the periods of investigation were compared to determine whether the slipping, the pinning, or the initial instability of the markers affected the growth rate. Body height was measured at the time of PCF diagnosis in each patient and compared with the body-length charts of Karlberg & Taranger (1976).

F. THERAPY

Peroperative and postoperative complications were searched for in clinical and radiographic reports.

The patients were followed-up by questionnaire and clinical and radiographic examination on an average 28 years after surgery (range 16-32 years in osteotomy series, 20-42 years in nail/pin series) (Hägglund et al. 1986a, Hägglund et al. 1986c). The clinical state was classified according to Charnley (1979) based on the system of d'Aubigné and Postel (1954) (Table 2). The degree of slipping was classified according to Bianco

Table 2. Classification of function according to Charnley (1979)

	<u>Pain</u>	<u>Motion</u>	<u>Walking</u>
1.	Severe and spontaneous	< 30	Few yards or bedridden Two sticks or crutches
2.	Severe on attempting to walk	30-60	Time and distance very limited with or without canes
3.	Tolerable, permitting limited activity	60-100	Limited with one cane (< than 1 hour). Difficult without a cane. Able to stand long periods
2.	Only after some activity. Disappears quickly with rest	100-160	Long distances with one cane. Limited without a cane
5.	Slight or intermittent. Pain on starting to walk but becoming less with normal activity	160-210	No cane, but a limp
6.	No pain	> 210	Normal

Table 3. Classification of slipping according to Bianco (1966)

0 = No slipping		
1 = Mild slipping	Displacement <1/3	} Of the diameter of the base of the bony epiphysis
2 = Moderate slipping	1/3-2/3	
3 = Severe slipping	>2/3	

Table 4. Classification of arthrosis according to Ahlbäck's classification of gonarthrosis

0 = No arthrosis	
1 = Mild arthrosis	Reduction of articular space
2 = Moderate arthrosis	Obliteration of articular space
3 = Severe arthrosis	Bone attrition

(1966)(Table 3), in most cases using the calcar femorale (Hansson et al. 1986). Anteroposterior, lateral, and Lauenstein projections were used, and the calcar femorale was visualized with fluoroscopy. Arthrosis was classified according to Ahlbäck's classification of gonarthrosis (1968, Table 4).

On the anteroposterior projections, the articulothrochanteric distance was measured according to Edgren (1965, Figure 3) in order to discover growth disturbances of the subcapital growth plate.

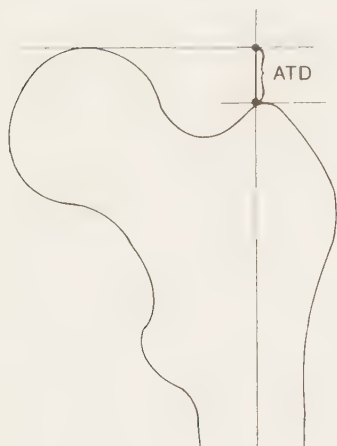


Figure 3. The articulothrochanteric distance. Redrawn from Edgren (1965).

G. STATISTICAL METHODS

Depending on the variables one of the following methods were used: Student's t test, chi-square test, Poisson distribution, or direct calculations using Gaussian approximation.

The following levels of significance were used:

***	= $p < 0.001$	Highly significant
**	= $p < 0.01$	Significant
*	= $p < 0.05$	Almost significant
NS	= $p > 0.05$	Not significant

IV Results and comments

A. RADIOGRAPHY

In the anatomic specimens the calcar femorale was usually seen as a distinct lamella in projections between 40 and 70 degrees of external rotation. From the level of lesser trochanter and 3 cm proximally, the structure was almost straight and parallel to the central axis (Figure 1). In the normal hips, there was a constant relation between the calcar femorale and the central axis (Table 5) at the level of the lesser trochanter and 3 cm proximally. By using the mean values from the first normal group (Table 5), the central axis was constructed from the calcar femorale. The distances between this calculated axis and the center of the femoral head demonstrate the accuracy of the method in the first normal group and the reliability of the normal mean values in the second normal group (Table 6).

When constructing the central axis from the calcar femorale in the PCF material using the mean values from the first normal group, the distance between this axis and the center of the femoral head depicts the

Table 5. Distance (mm) between calcar femorale and central axis at different levels (according to Figure 1) in 36 male and 44 female hips (first normal group)

	Males		Females	
	M	SD	M	SD
At level of lesser trochanter	11.1	3.4	10.0	3.3
1 cm proximal	11.2	3.1	9.9	3.0
2 cm "	11.4	2.8	10.1	2.8
3 cm "	12.2	2.4	10.7	2.4
4 cm "	14.6	3.7	12.0	2.4

Table 6. Error of the radiographic method. Positive value means displacement/angulation below predicted central axis

	First normal group				Second normal group			
	Males		Females		Males		Females	
	M	SD	M	SD	M	SD	M	SD
Displacement of caput center in mm (d)	0.2	2.4	0.0	2.3	-0.7	2.0	0.3	1.9
Angular deviation in degrees (v)	0.1	3.5	0.1	3.3	-1.9	4.8	-0.7	3.6

Both d and v according to Figure 2.

displacement of the epiphysis. Both displacement and angular deformity (Figure 4) increased with degree of slipping according to Bianco (Figures 5 and 6). A displacement of 1 mm corresponded to a deviation of about 2 degrees in males and about 2.5 degrees in females. Of the contralateral hips judged as normal, the center of the femoral head was displaced 2.7 ± 3.9 mm in males (**) and 4.5 ± 3.5 mm in females (***). The angular deviation was 3.5 ± 5.7 degrees in males (**) and 8.2 ± 5.1 degrees in females (***).

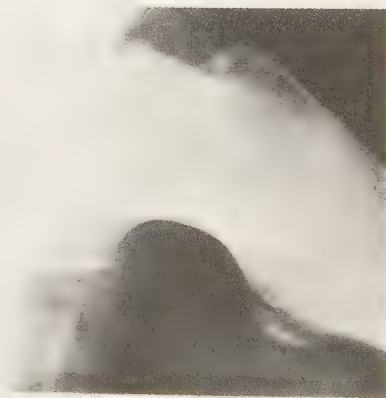
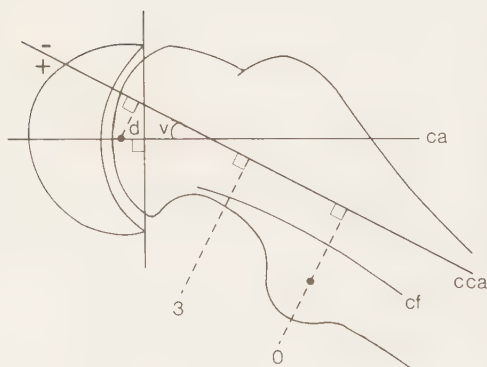


Figure 4. Calcar femorale (cf) with calculated central axis (cca) in PCF. Ca = central axis drawn from the center of the femoral head. d = displacement of femoral head. v = angular deviation.

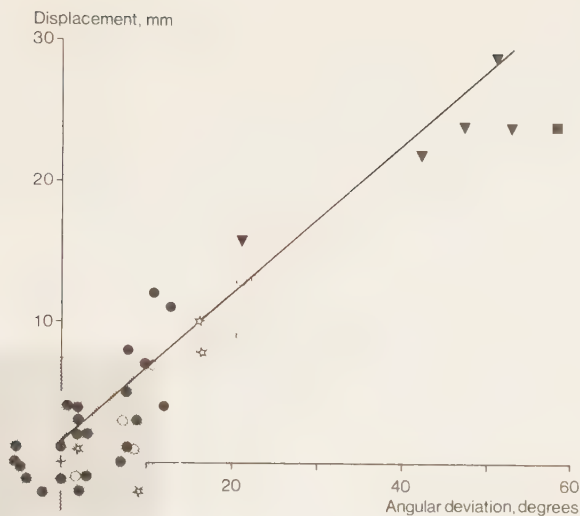


Figure 5. Displacement and angular deviation of femoral head in 36 males with PCF (67 hips). Grey area shows mean value ± 3 SD in first normal group. $y = 0.8 + 0.53x$, $r = 0.89$. ● = normal contralateral hip; ☆ = asymptomatic slipping; ○ = mild slipping; ▼ = moderate slipping; ■ = severe slipping.

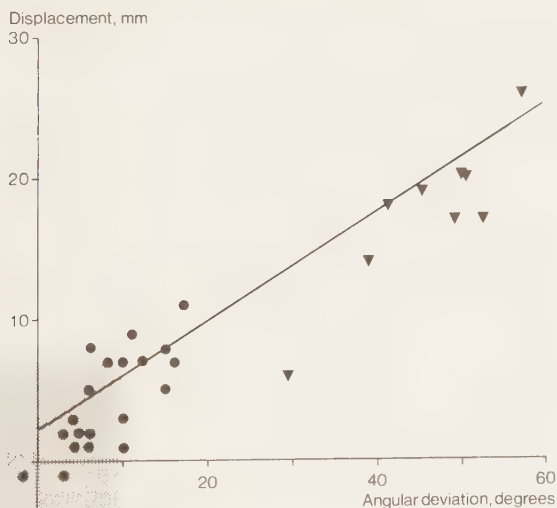


Figure 6. Displacement and angular deviation of femoral head in 22 females with PCF (41 hips). Same symbols as in Figure 5. $y = 1.4 + 0.39x$, $r = 0.92$.

COMMENTS The constant relation between the calcar femorale and the femoral head in normal hips provides a method for predicting the original position of the femoral head from the course of the calcar femorale. The calcar must, however, be distinctly visualized. A Lauenstein projection is usually sufficient, but radiography in combination with fluoroscopy is advantageous.

The calcar femorale persists without evident change of position throughout life (Griffin 1982). The structure represents a reinforcement (Harty 1957), reflecting the biomechanics of the hip (Frankel 1960). The slip usually occurs at almost a right angle to the calcar femorale.

Examination of the contralateral hips without known history of hip disease of the PCF patients revealed a minor displacement of the center of the femoral head in several hips (Figures 5 and 6). This displacement could be due to undiagnosed minor slippings.

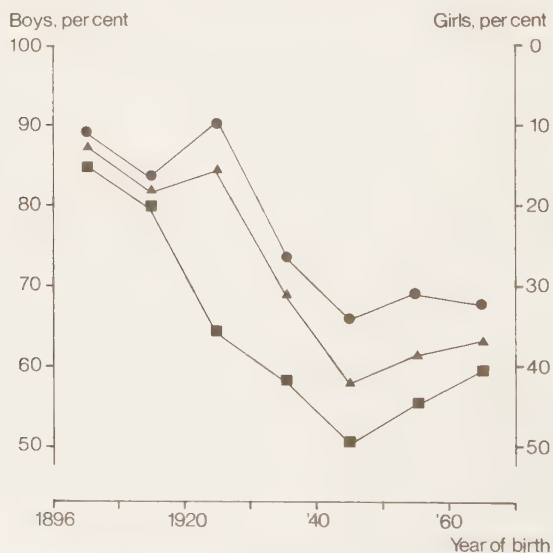


Figure 7. Sex distribution in relation to year of birth and place of residence. ● = living in cities; ▲ = living in rural areas; ■ = total.

B. EPIDEMIOLOGY

1. Sex distribution

In total, 372 cases (70%) were boys and 160 (30%) girls. The male preponderance has decreased from 85-90% to 60-65% during the period of investigation (Figure 7). During the whole period, the male preponderance was greater among those living in rural areas when compared with those living in cities.

COMMENTS The male preponderance agrees with most earlier investigations (Wilson et al. 1965, 71%; Henriksson 1969, 65%; Kelsey et al. 1970, 67%; Engelhardt 1984, 66%).

Morscher (1968), in rats, found that the growth plate could be more easily disrupted during periods of rapid growth. The growth spurt is greater in boys and lasts for a longer period (Deming 1957). In addition, boys are more vulnerable at a later chronologic age than are girls, and they weigh more at the time of maximum vulnerability.

Animal experiments (Morscher 1968) have shown that estrogen increases the strength of the growth plate. The same experiments indicate that androgen during earlier periods of sexual maturation decreases physeal strength, whereas in high doses over a prolonged period of time androgen increases physeal strength.

The divergences could also be a consequence of differences in physical activity with time and place of residence. In the earlier years of the present century, boys in puberty were often working. Symptoms in boys were probably taken more seriously, and more boys with PCF received qualified medical care. Currently, the children in puberty, both boys and girls, are still in school and are given a medical examination regularly.

2. Age at slipping

The mean age at onset of symptoms was 14.4 years (SD 2.1; range 5.4-23.4 yrs) in the boys and 12.2 years (SD 1.7; range 5.4-22.6 yrs) in the girls

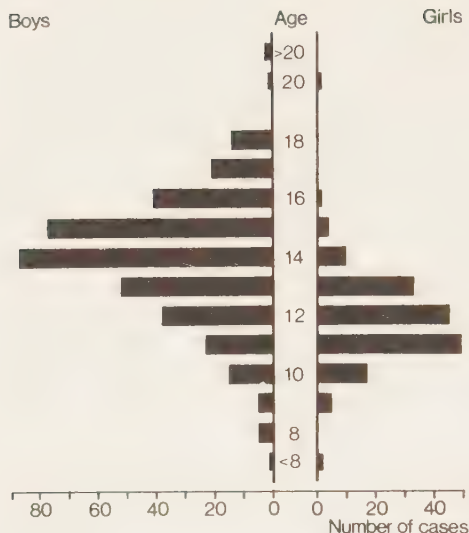


Figure 8. Number of cases in different age groups.

(Figure 8). However, the mean age has gradually decreased: in boys from 16 ± 1.5 years (1896-1909) to 12.7 ± 1.6 years (1960-1969)(***) and in girls from 12.6 ± 2.3 years (1910-1939) to 11.8 ± 1.1 years (1950-1969)(*) (Figure 9). No difference in relation to place of residence was found.

Four cases had their onset of symptoms at 20-24 years of age. One female with left-sided slipping at aged 20 years and right-sided slipping at aged 24 years had a cerebral tumor compressing the hypothalamus. She had no signs of pubertal development. One male had hypothyreosis, whereas two other males were both described as having had late pubertal development, but no endocrinologic investigations were conducted.

COMMENTS During the first years in the investigative period, there could have been some cases of PCF at an early age that missed registration. There are probably also some individuals born in the 1960s who have not developed PCF by 1982. These cases could influence, to a smaller extent, the mean ages in the corresponding age periods. However, even when comparing those born between 1910 and 1919 with those born between 1950 and 1959, the decrease in afflicted boys is significant(***)

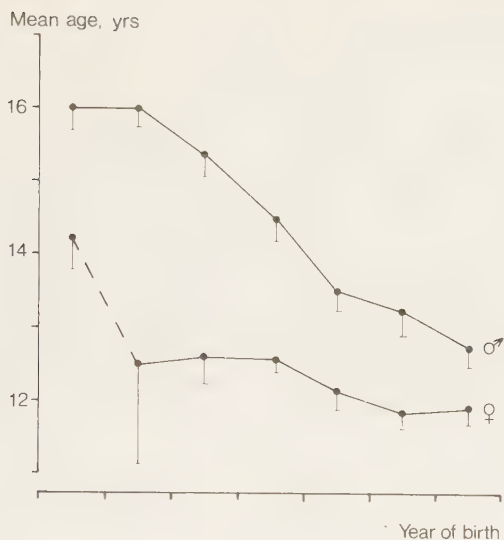


Figure 9. Mean age (with standard error of mean) at onset of symptoms in relation to sex and year of birth.

The age of pubertal development has decreased during the last century (Karlberg & Taranger 1976). Comparisons among various ages of menarche indicate a decrease of 4 to 5 months per decade. The first pubertal changes take place about 1 year earlier in girls, whereas the sex difference in peak height growth velocity is about 2 years (Karlberg & Taranger 1976).

The decreasing age at onset of PCF is probably also in part accounted for by an increased awareness in the social environment, leading to recording of even minor initial symptoms.

3. Delay in diagnosis

The average duration between onset of symptoms and diagnosis was 4.8 months in boys and 3.4 months in girls. The average diagnostic delay decreased by about 1 month in both boys and girls during the period of this investigation (Figure 10).

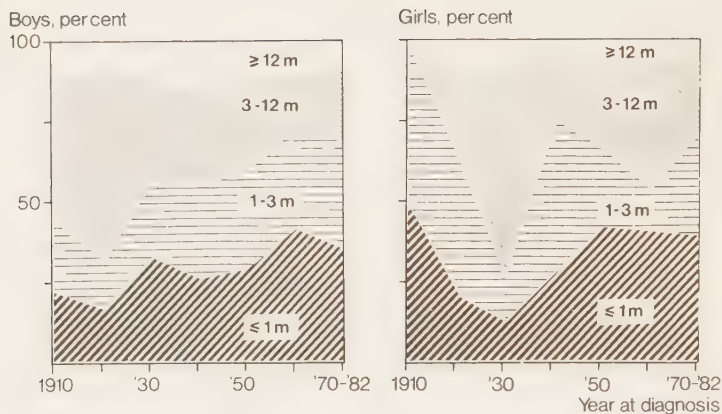


Figure 10. Number of cases related to time (months, m) between onset of slipping and diagnosis.

COMMENTS Despite expanding health care during this century, the diagnostic delay has only slightly diminished. About 40 per cent of the males and 35 per cent of the females still have a history of pain or limping exceeding 3 months before diagnosis.

4. Side and bilaterality

In both sexes the left hip was affected more often than was the right one (Table 7). However, during the past few decades there has been a tendency (*) towards equalization.

Table 7. Side affected at primary admission. Number of cases, percentage in brackets

	Left	Right	Bilateral	Total
Males	243 (65)	111 (30)	18 (5)	372
Females	96 (60)	60 (37.5)	4 (2.5)	160
Total	339 (64)	171 (32)	22 (4)	532

At primary admission, 18 boys and 4 girls of the 532 children had a bilateral PCF. Later, during adolescence, 45 boys and 14 girls had a contralateral symptomatic slip, and 24 boys and 7 girls had an asymptomatic slip. During the last 7 years, 30 boys and 19 girls were prophylactically pinned in their contralateral hip. Excluding these, it appears that totally 25 per cent of the boys and 18 per cent of the girls had a bilateral PCF diagnosed during adolescence.

Boys living outside cities had a higher risk of sustaining bilateral slipping (30%) than boys living in cities (17%)(**). In girls the situation was the opposite one (NS).

COMMENTS Earlier investigations have demonstrated a preponderance of PCF in the left hip in boys in cases primarily unilateral (Oram 1952, 62%; Burrows 1957, 69%; Sørensen 1968, 66%; Engelhardt 1984, 59%). In girls the left-side dominance is less accentuated, and some investigations show no difference at all (Burrows 1957, Sørensen 1968)

Marsk (1958) found that right-handed persons put more weight on their left leg than on their right one. Dunn (1975) explained the left-side predominance by the fact that right-handed children sit more on the left buttock when writing, and thus aggravate the condition by congesting the retinacular veins of the femoral neck.

In children with leg-length discrepancy before puberty, the left leg is shorter in about 80 per cent, whereas after puberty the left leg is longer in most cases (Hult 1954, Willner 1972, Johnsson 1983). This may indicate that during puberty the average growth rate is greater in the left than in the right leg.

5. Seasonal variation

In 294 boys and 139 girls, the month of onset of symptoms could be determined (Figure 11). In the boys no significant variation was noted. In the girls 46 per cent had their onset of symptoms during the 4-month

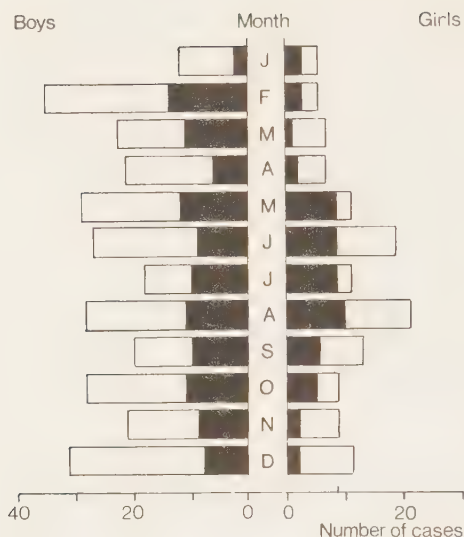


Figure 11. Number of cases related to month of onset of slipping. ■ = < 1 month between onset of slipping and diagnosis; □ = > 1 month between onset of slipping and diagnosis.

period May-August. Regarding only females with less than 1 month between onset of symptoms and diagnosis, 59 per cent occurred between May and August (**).

COMMENTS The rate of growth in length in adolescence is greatest in the spring and summer (Tanner 1962, Kärrholm et al. 1983), which may result in decreased physeal strength during this period, but there is no explanation of the sex difference.

6. Incidence

The incidence (No./10,000) was calculated as the number of PCF cases born in a specific year in relation to the number of births of that year (Figure 12). The average incidence in boys was 6.1 (range 0-25.7) and in girls 3.0 (range 0-20.5). In those born between 1930 and 1965, the average incidence was 7.1 in boys and 5.3 in girls. Boys living in the country have always been at higher risk (7.5) than those living in cities (4.8)(**)(Figure 13). In girls the rural/urban relation has varied.

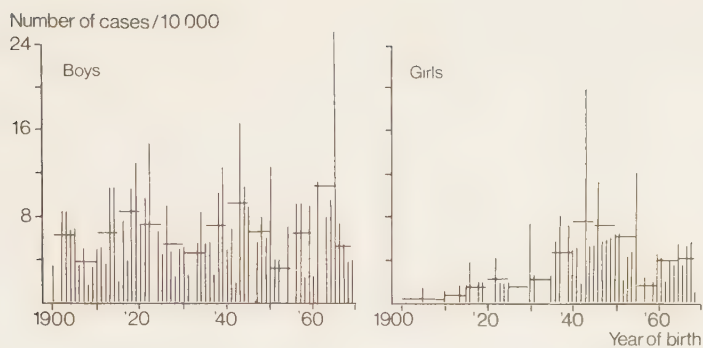


Figure 12. Incidence related to year of birth. Mean values over 5-year periods indicated.

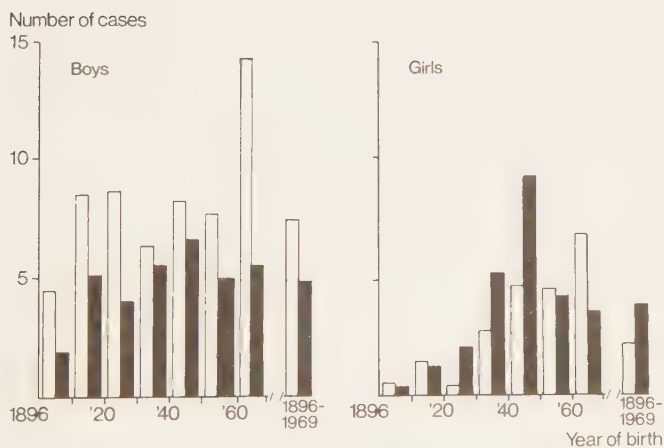


Figure 13. Incidence related to year of birth and place of residence. □ = living in cities; ■ = living in the country.

COMMENTS The results from earlier incidence calculations of PCF (Waldenström 1939, Henriksson 1969, Kelsey et al. 1970) are difficult to use because they are based on a heterogeneous population, 2-25 years of age, where the frequency is calculated per year, not taking into consideration the low risk in the younger and in the older age groups. In the present investigation, the incidence is presented as the number of cases with PCF during the entire growth period in relation to the number of males and females born in the same year. The figures should be regarded as minimum values because there are probably cases of PCF that have never been diagnosed for various reasons. The mortality rate between birth and puberty is very low and could be disregarded. Change of residence during the years up to the onset of PCF is believed to be low and of minor importance.

Jerre (1950), in his material containing patients with onset of symptoms between 1917 and 1945, found a higher incidence of PCF in the later years and explained this on the basis that people in the earlier periods did not seek medical advice as often as they did during the later years. It was also explained by an improved diagnostic awareness of PCF among nonspecialists and more frequent consultations with orthopedic surgeons during the later period.

Henriksson (1969) found a decreasing incidence of PCF during his period of observation, 1947-1966 and attributed this to the higher standard of living in the later years, including better nutrition during childhood.

Our investigation demonstrates and confirms the same pattern of increase and decrease as that found by others studying the same periods. The long-range follow-up shows, however, that Jerre and Henriksson have analyzed a periodic incidence pattern of PCF in different phases. The decreasing tendency that Henriksson found during the 1960s has been followed by an increasing tendency during the 1970s, which makes the hypothesis about nutrition untenable.

The average incidence of PCF during the latter part of investigation is higher than that during the first part. As Jerre (1950) postulated, this is probably because especially girls with minor symptoms did not seek qualified medical advice before 1930. However, there were still some children born in the 1960s who had not demonstrated symptoms of PCF by 1982.

It appears (Figure 13) that the incidence of PCF follows a periodic pattern with peaks approximately every 20th year. The same periodicity is seen both in boys and girls. The incidence, calculated over 5 years, differed by a factor of two to three between the highest and lowest values (***).

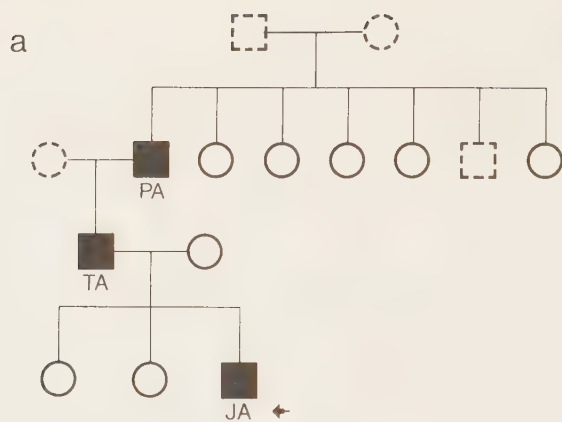
The cause of the periodic incidence pattern remains obscure. Perhaps nutritional or environmental factors with the same periodicity affect patients who are at a risk of contracting PCF. Factors discussed earlier are fluorides in drinking water (Kelsey & Keggi 1971) and aminonitriles in cow's milk (Ponseti & McClintock 1956, Andrén & Borgström 1958), but no absolute evidence has been presented.

C. ETIOLOGY

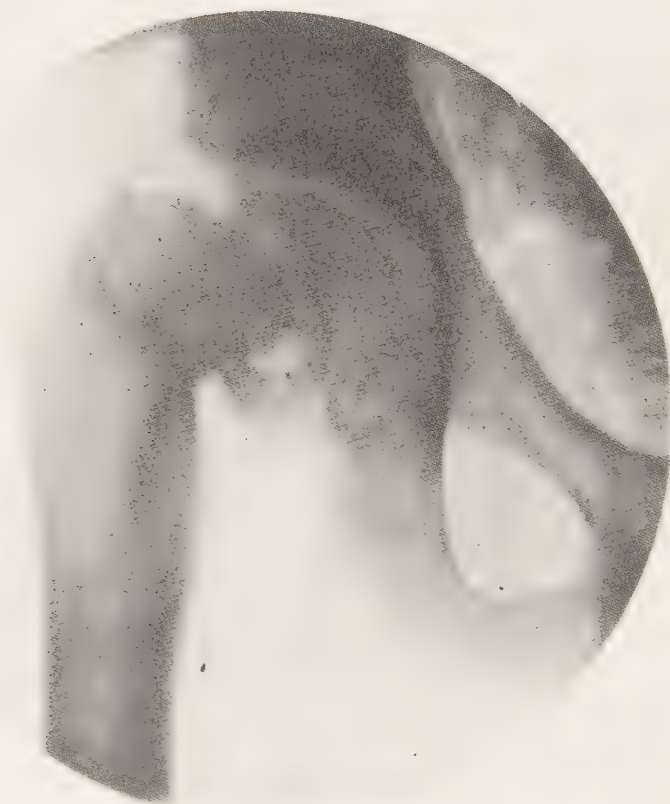
1. Heredity

The series of 50 consecutive cases contained two sisters; thus 49 families were investigated. Two parents had died; another was unavailable; and 10 relatives were only interviewed, none of whom had hip complaints.

In three families a first-degree relative was treated for PCF: the two sisters in the series, one father, and one brother. In four families there was a second-degree relative who had been treated for PCF. In one family, both a first- and a second-degree relative were treated for PCF (Hägglund & Hansson 1986, Figure 14).



b



c



d



Figure 14a. Family tree showing PCF in three generations.
 ■ = PCF; ○ = Normal; [] = Not examined.

b. PA, treated with hip plaster spica.

c. TA, Johansson nailing.

d. JA, hook-pinning bilaterally (prophylactic pinning of the left hip).

Table 8. Radiographic findings in first degree relatives of patients with PCF

Conventional evaluation	Not examined	Normal	Suspected PCF	PCF	Total
Relation femo- ral head-calcar femorale ^c	Not examined	<3 SD ^a	>3 SD PCF		
Fathers	5	37	5	2(+1) ^b	49
Mothers	4	38	7		49
Brothers	3	33		1	37
Sisters	1	25	2	1	29
Total	13	133	14	4(+1) ^b	164

a. Including 38 hips without distinctly visualized calcar femorale.

b. One family with PCF in two sisters and their father.

c. Displacement > 3 SD was judged as PCF (Hansson et al. 1986).

At examination a marked bilateral slipping was found in the father of the two sisters treated for PCF (Table 8). In another 14 first-degree relatives, both the radiographic appearance and the femoral head/calcar femorale relationship were highly suspect for PCF. In all of these hips the femoral head in relation to the calcar femorale was displaced >3 SD dorsomedially (Chapters IIIA, IVA).

Totally, there was an obvious additional first-degree relative who was afflicted with PCF in four of the 49 families. When including the second-degree relatives, there were 2 individuals or more with PCF in seven families. If the highly suspect hips are included, 17 families had 2 members or more with PCF.

COMMENTS Earlier investigations on the hereditary transmission of PCF are all based on questionnaires or clinical reports; both Jerre (1950) among 153 cases and Wilson et al. (1965) among 240 cases found a 5 per cent incidence of PCF among close relatives. Finally, Rennie (1982) found a 14.5 per cent incidence of PCF among relatives.

In our investigation, six families (12%) had more than one known member with PCF before the radiographic examination, corresponding to the previously presented results. The radiographic examination, however, revealed signs of slipping in members of another 11 families, indicating an accumulation of the disease in about one third of the families.

2. Body weight and height

None of the patients included had a known hormonal or metabolic disorder.

The average age at peak height velocity (PHV) was 13.7 ± 1.3 years in the boys and 12.9 ± 1.0 years in the girls, which is 0.32 SDS above normal in boys and 0.96 SDS less than normal in girls (Table 9). The onset of slipping (hip symptoms) occurred on an average 1.1 years before the age at PHV, both in the boys and in the girls, i.e., during the period of increasing height gain during adolescence (Figure 15). Five children had their onset of symptoms before this age at increasing growth and six children after the age at PHV.

Mean attained height 2 years before age at PHV was significantly increased in both sexes also after adjustment for the individual age at PHV (Table 9). However, at maturity the height was only slightly (NS) above

Table 9. Growth pattern in 24 males and 16 females with PCF, expressed in standard deviation scores - SDS (mean, SD)

	Males			Females		
	M	SD		M	SD	
1 Age at peak height velocity (PHV)	0.3	1.2	NS	-1.0	1.1	**
2 Height 2 years before PHV	1.1	1.3	***	0.7	0.9	**
3 Same as 2, adjusted for age at PHV	0.9	1.4	**	0.9	1.0	**
4 Height at maturity	0.5	1.2	NS	0.1	0.9	NS
5 Pubertal gain (diff. 4-3)	-1.0	1.4	**	-1.8	1.7	***
6 Weight for height 2 years before PHV	3.1	1.9	***	1.9	1.5	***
7 Weight for height at maturity	2.3	1.3	***	2.3	1.8	***

Two-tailed t test. NS = not significant, ** = $p < .01$, *** = $p < .001$.

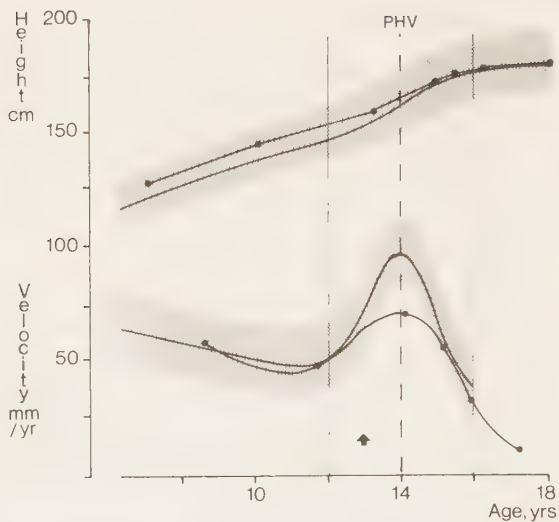


Figure 15. A typical growth pattern for a child (boy) with PCF. Reference values with ± 2 SD given in terms of the ICP model. Arrow depicts onset of symptoms. Age at peak height velocity (PHV) ± 2 years indicated.

normal. Mean midparental heights were also almost normal, and adjustment for midparental height thus did not affect the mean heights at maturity. Average pubertal gain was, accordingly, lower than normal: - 0.96 SDS in the boys (**) and - 1.84 SDS (***) in the girls.

The typical growth pattern found in these children with PCF is exemplified by one of the boys in Figure 15. This growth pattern, with an above average height before onset of puberty and a reduced pubertal gain, was found in 20 of the boys and in 14 of the girls. Four boys and two girls had an above average pubertal gain in height.

Weight for height, also expressed in SDS, was significantly increased at 2 years before the age at PHV (+ 3.13 SDS in males and + 1.85 SDS in females), and remained increased up to the age at maturity (***)(Table 9). The individual differences in weight for height at these two ages were tested and found to be not significant.

COMMENTS An important feature of the ICP growth model is that it strongly accords with what is known about the endocrinologic regulation of longitudinal growth (Karlberg 1986). The childhood component seems to be dependent mainly on growth hormone (GH), but to a less extent on thyroid hormone. The pubertal component, on the other hand, has been taken into account for the contribution of growth, effected by sexual hormones: testosterone in males and estrogens in females. The abnormal growth pattern before and during puberty in these PCF patients could be due to a disturbed hormonal regulation.

Animal experiments (Morscher 1968) have shown that the physis is weakened during periods of rapid growth. The time at the onset of symptoms was in the majority of cases during the period of increasing growth at the initial phase of the pubertal growth spurt. Because many slippings are asymptomatic (Hägglund et al. 1986c), the 5 cases with onset of symptoms after PHV could have had their onset of slipping before this age.

3. Longitudinal bone growth

The average skeletal age in the boys was 0.5 ± 1.0 years lower than the chronologic age. In the girls the average skeletal and chronologic ages were the same (0.0 ± 0.6 years). In the following presentation skeletal age has been used. There was no difference in growth rate between the first and the second of the periods of investigation. Consequently, all periods were used in the study.

The measured mean growth rate in boys with PCF corresponded to the mean growth rate in normal boys, especially after about 12.5 years of age (Figure 16). The mean growth rate before this age was based on only 4 cases.

One boy at the age of 11 years sustained a right-sided ankle fracture, and the distal fibula and tibia on both the fractured and the intact sides were followed up by RSA (Figure 17). His skeletal age was about 14 years at the chronologic age of 11 years and 3 months. Four months after the

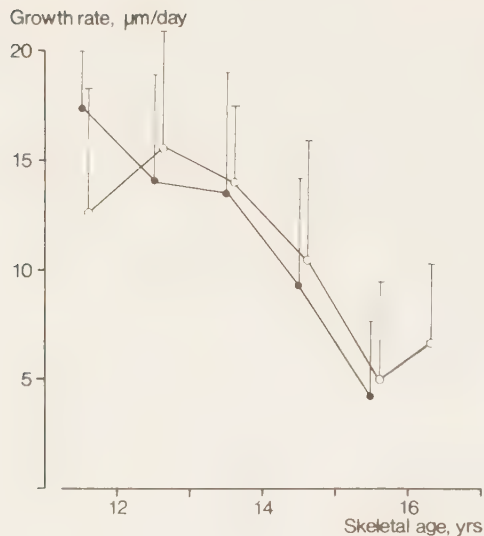


Figure 16. Mean growth rate with SD in the distal fibula in normal boys (●) and boys with PCF (○).

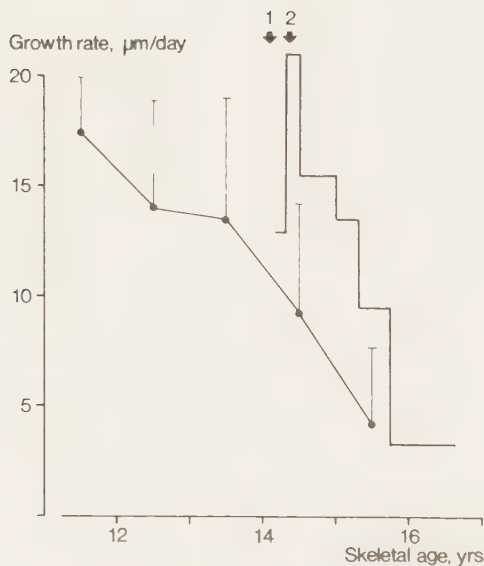
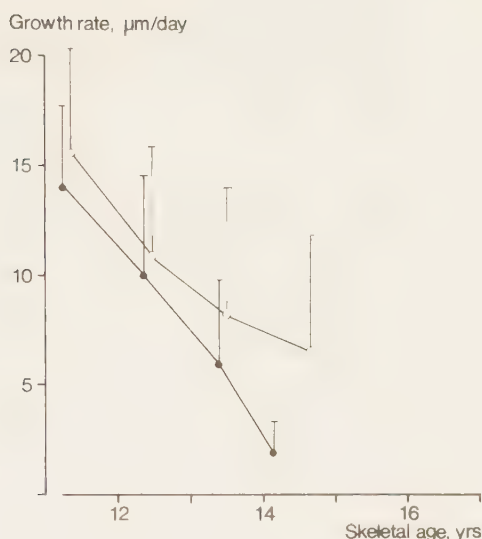


Figure 17. Growth diagram of the left distal fibula in a boy who sustained a fracture on the right ankle (arrow 1) and subsequently developed symptoms of PCF bilaterally (arrow 2). Mean normal growth rate with SD indicated.

Figure 18. Mean growth rate with SD in the distal fibula in normal girls (●) and girls with PCF (○).



ankle fracture, he experienced mild pain in both hips, but did not report his symptoms. Ten months later, bilateral PCF was diagnosed. At onset of symptoms, his growth rate in the intact left distal fibula was about 21 $\mu\text{m}/\text{day}$ (expected about $9 \pm 6 \mu\text{m}/\text{day}$). After about 1 year, his growth rate was almost normal.

In the girls the average growth rates were slightly higher as compared with the normal growth charts (Figure 18), but these differences were not significant.

Body height at the time of diagnosis in relation to normal body length charts is presented in Table 10.

COMMENTS The recorded growth rates were almost normal. Because the accuracy of the RSA method is very high ($\pm 30\text{--}50 \mu\text{m}$ per measurement, corresponding to $1\text{--}2 \mu\text{m}/\text{day}$, Selvik et al. 1983; Kärrholm et al. 1984), the SD in the results mainly represents the individual variations in growth rate.

Table 10. Body height related to normal at PCF diagnosis
in 22 boys and 10 girls

		>-1 SD ≤+1 SD	>+1 SD ≤+2 SD	>+2 SD
Chronologic age	boys	13	5	4
	girls	6	4	
Skeletal age	boys	9	6	7
	girls	6	4	

However, 13 children (17 when adjusted for skeletal age) had a body height exceeding the mean value by more than 1 SD at the time of diagnosis. Thus, before diagnosis, these children must have had a higher than average growth rate. This is supported by the result from the boy (Figure 17) with growth measurements also before the slipping (Kärrholm et al. 1982).

There is normally a seasonal variation in the growth rate (Tanner 1962, Kärrholm et al. 1983), with a higher rate during spring and summer. Most patients with PCF have their initial symptoms during the same period (Hägglund et al. 1984). This indicates that PCF could be associated with a temporarily increased general growth rate.

In conclusion, there are indications that the skeletal growth rate is slightly accelerated before slipping and fairly normal after slipping.

D THERAPY

1. Nailing - pinning

In the 172 patients, 204 hips were nailed or pinned. The three-flanged stainless steel Johansson nail or a Vitallium[®] nail of essentially the same type (Figure 19) was used in 116 hips. The Nyström pin made of stainless steel or of Vitallium[®] was used in 88 hips. Totally, 179 hips were operated on without reduction and 25 hips with reduction (23 closed, two open).

Figure 19. Johansson nail (left) and Nyström pin (right).



Early complications (Table 11). Peroperative physeal separation and displacement of the epiphysis was described in 11 hips after nailing and in two after pinning. The nail/pin was withdrawn about 5-10 mm in five hips. In two hips the nail was extracted and replaced with a Nyström pin. The diastasis was eliminated by hammering on the trochanteric area in three hips. In the remaining three hips the diastasis was left, but disappeared soon after surgery.

Table 11. Early complications in 116 nailed and 88 pinned hips

	<u>Nailed</u>	<u>Pinned</u>	<u>Total</u>
Physeal separation	11	2	13
Perforation of subchondral bone	4	3	7
Fracture	4	0	4
Segmental collapse	5	3	8
Chondrolysis	0	0	0
Lost epiphyseal grip due to sliding	8	5	13
Lost epiphyseal grip due to growth	1	13	14

The complications listed above occurred in 29 nailed and 24 pinned hips.

Perforation of the subchondral bone of the femoral head was recorded in four hips after nailing and in three hips after pinning. In all cases the nail/pin was withdrawn 5-10 mm. In one male the guide wire broke when the surgeon was driving in the nail. The proximal part, which did not penetrate the subchondral bone, was left in the bony epiphysis.

Deep infection was noted in 2 patients. Both infections healed without sequelae after operative drainage and nail extraction.

The femur fractured at the level of the base of the nail in four hips after Johansson nailing 3, 12, 12, and 13 months, respectively, after operation. In all instances the fracture was due to trauma.

Segmental collapse was recorded in five hips after nailing and in three hips after pinning. Half of these patients had had closed reduction performed prior to osteosynthesis.

Lost epiphyseal grip due to sliding of the nail/pin before physeal closure was recorded in eight hips after nailing and in five hips after pinning. Renailing/pinning was performed in 11 hips. In three hips there was sliding of the reinserted nail/pin, and a third operation with nailing/pinning was performed. In two children the nail was extracted. One of these sustained maximum slipping and was reoperated on by femoral neck osteotomy 3 years after the primary operation.

Table 12. Number of patients operated on by nailing/pinning

	Patients	Hips				
		Total	Nailed	Pinned	In situ	Reduction
Primary material	172	204	116	88	179	25
Dead at follow-up	7	8				
Excluded	1	1				
Unidentified	11	14				
Questionnaire	153	181	101	80	161	20
Reexamined	132	157	87	70	140	17

Lost epiphyseal grip due to the growth in length of the femoral neck was seen in one hip after nailing and in 13 hips after pinning. All 14 hips were reoperated on by fixation with a longer nail or pin. Three pinned hips required another reoperation and a longer pin.

Follow-up. Of the primary sample of 172 cases, 153 were reviewed by questionnaire and 132 were clinically and radiographically reexamined (Table 12). Owing to severe arthrosis, three males had been operated on using arthrodesis, McMurray osteotomy, and total hip replacement, respectively. In these cases preoperative radiographs and information on hip function were used for evaluation.

Hip function at follow-up is presented in Table 13. The four hips with pain at rest and the seven hips with a total range of motion below 100° all had grade 3 arthrosis.

Among the 132 patients examined radiographically, 220 hips showed slipping. Eighty-eight patients (67%) had bilateral slipping; and of these, 55 were not diagnosed during adolescence; further, arthrosis was seen in 16 of these undiagnosed slippings (Table 14). There were more nailed than pinned hips with severe slipping (Figure 20), and more hips with severe slipping during the earlier years (Figure 21).

Table 13. Hip function 28 (20-42) years after nailing/pinning

Grade		1	2	3	4	5	6	Total
Pain	in situ	3	11	15	13	3	116	161
	reduction	1	6	4	1	1	7	20
Motion	in situ	1	2	2	19	66	50	140
	reduction	2	2	1	3	8	1	17
Walking	in situ			1	8	24	128	161
	reduction		1	1	4	2	12	20

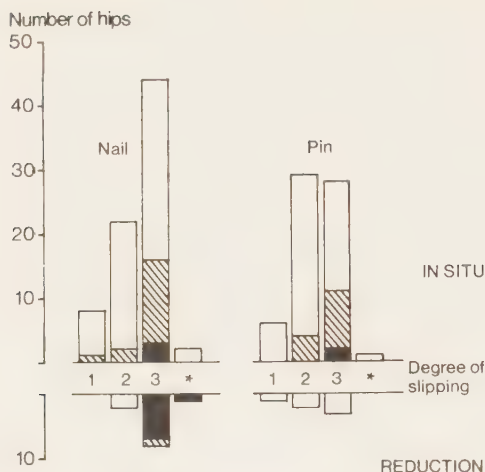


Figure 20. Arthrosis in relation to nailing/pinning and degree of slipping in 157 nailed/pinned hips. In reduced hips, degree of slipping at follow-up. ★ = slipping, classification not possible. □ = No arthrosis; ▨ = Grade 1 arthrosis; ■ = Grade 3 arthrosis. (No hip with grade 2 arthrosis at follow-up).

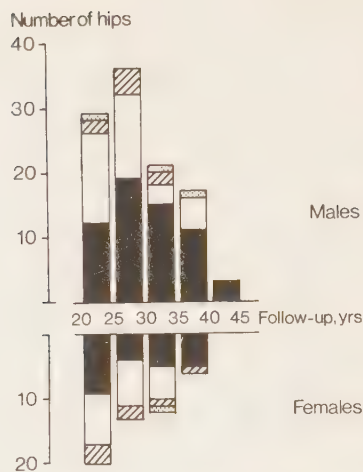


Figure 21. Slipping in relation to follow-up time in 157 nailed/pinned hips. In reduced hips degree of slipping at follow-up. ▨ = mild slipping; □ = moderate slipping; ■ = severe slipping; ▨ = slipping, classification not possible.

Table 14. Slipping and arthrosis 28 (20-42) years after nailing/pinning

	Total no. of hips	Slipping					Arthrosis			
		0	1	2	3	*	0	1	2	3
Nailing/pinning in situ	140		14	51	72	3	106	29		5
Nailing/pinning with reduction	17		1	4	11	1	8	1		8
Slipping diagnosed at follow-up	55		39	14	2		39	15		1
No slipping at follow-up	44	44					42	2		
Total	256	44	54	69	85	4	195	47		14

* Slipping, classification not possible.

Eight hips with other methods of treatment in the contralateral hip excluded.

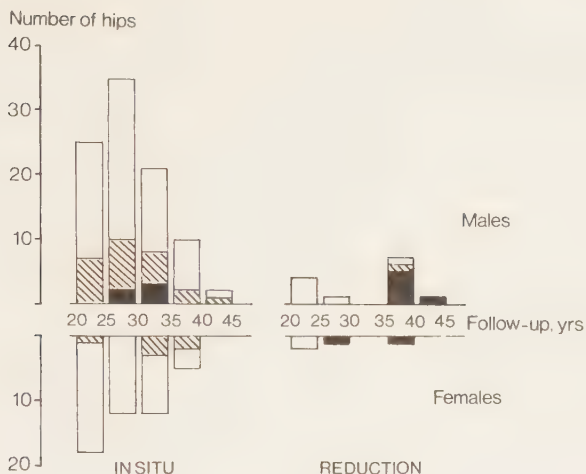


Figure 22. Arthrosis in relation to follow-up time in 157 nailed/pinned hips. Same symbols as in Figure 20.

Arthrosis was seen in 43 of the 157 nailed/pinned hips at follow-up: 34/140 after fixation in situ and 9/17 after fixation with reduction (Table 14). Frequency and severity of arthrosis increased with degree of slipping (Figure 20). However, among those operated on without reduction, there was no increased arthrosis with time during the period 20-40 years after surgery (Figure 22). Seven of the nine patients operated on with reduction more than 35 years ago had severe arthrosis (Figure 22).

The radiographic findings in the cases with various early complications (Table 15) showed that only segmental collapse was correlated with arthrosis.

The position of the nail or pin in relation to the anticipated position of the growth plate was analyzed in the 74 hips with the nail/pin left at follow-up. In 16 out of 43 nailed hips and in 12 out of 25 pinned hips, the nail/pin ended distally to the physeal scar and in another six hips the relation was doubtful. However, no correlation between nail/pin position and slipping or arthrosis was seen (Table 15).

Table 15. Slipping and arthrosis at follow-up in relation to early complications in 157 nailed/pinned hips

	Slipping				Arthrosis				Total
	1	2	3	*	0	1	2	3	
Physeal separation	3	6	1		9	1			10
Perforation of sub-chondral bone	1		4		3	2			5
Fracture		1	2		1	2			3
Segmental collapse	1	1	2	1	2			3	5
Lost epiphyseal grip due to sliding	2	5	4		9	2			11
Lost epiphyseal grip due to growth	2	8	3	1	13	1			14

* Slipping; classification not possible.

The complications listed above occurred in 42 hips.

Table 16. Articulotrochanteric distance in mm (mean $\pm$ SD) related to treatment and degree of slipping. Number of follow-up cases in brackets. For comparison, results after no treatment and closed reduction and hip spica (Ordeberg et al. 1986b) are presented.

Normal values: 21 ± 7 mm (Ordeberg et al. 1986b)

	Slipping		
	Mild	Moderate	Severe
No treatment	17 $\pm$ 6.0 (9)	17 $\pm$ 9.8 (8)	8 $\pm$ 12.4 (38)
Closed reduction-hip spica	25 $\pm$ 7.1 (4)	14 $\pm$ 7.5 (11)	10 $\pm$ 7.4 (28)
Femoral neck osteotomy			12 $\pm$ 5.6 (27)
Nailing in situ	11 $\pm$ 10.3 (8)	16 $\pm$ 7.8 (23)	9 $\pm$ 6.5 (41)
Nailing, reduction		25 (2)	9 $\pm$ 11.0 (7)
Pinning in situ	20 $\pm$ 5.6 (6)	16 $\pm$ 5.6 (29)	13 $\pm$ 5.8 (28)
Pinning, reduction	35 (1)	18 (2)	15 $\pm$ 4.9 (3)

The articulothrochanteric distance was slightly decreased in the nailed mild slippings, when compared with pinning or nonoperative treatment (Table 16). There were also more nailed hips (eight) than pinned hips (two) with an articulothrochanteric distance >2 SD below the normal (Ordeberg et al. 1986b). However, no mean difference was seen between nailed and pinned hips with moderate or severe slippage.

Twenty-one former patients answered the questionnaire, but were not able to come for a reexamination. From the questionnaires the long-term results in these former patients seemed to correspond to those of reexamined patients: all walked unlimited distances, 14 were asymptomatic, 4 had pain only after some activity, and 3 of them experienced pain only initially when starting to walk. None of them had been operated on for arthrosis.

COMMENTS Early complications. Physeal separation was more frequent after osteosynthesis with the blunt Johansson nail than with the pointed Nyström pin. Contrary to the report by Wilson et al. (1965), this complication was not associated with segmental collapse or arthrosis.

Perforation of the subchondral bone is probably more frequent than has been recorded using AP and Lauenstein projections (Walters & Simon 1980, Bennet et al. 1984, Lehman et al. 1984). Perforation has been associated with chondrolysis (Walters & Simon 1980). In our investigation there was no identified case with chondrolysis secondary to perforation of the subchondral bone. At the follow-up examination, however, 2 patients out of 5 with previous perforation had grade 1 arthrosis.

Lost epiphyseal grip due to the growth in length of the femoral neck was considerably more frequent after pinning (Table 11). Probably there is greater damage to the physis when driving in the blunt nail, resulting in an increased risk of growth retardation and premature growth-plate closure. This theory is supported by the differences in articulothrochanteric distance found between the nailed and the pinned hips. After lost grip due to sliding

or growth in length, there is a risk of further slipping. Upon adding those reoperated on because of lost epiphyseal grip to those with the physeal scar proximal to the nail/pin at reexamination, it appears that, if diagnosed before physeal closure, about 45 per cent of nailed and 70 per cent of pinned hips require renailing/pinning before growth-plate closure to prevent reslipping. If nails or pins without satisfactory anchorage in the bony epiphysis are used, the patient must be followed radiographically up to growth-plate closure to avoid this complication. Correspondingly, the nail/pin must not be removed before growth-plate closure. In fact, the case excluded from follow-up because of secondary operation with femoral neck osteotomy should be regarded as a failure for this reason.

Segmental collapse was seen in four hips out of the 25 treated with reduction before nailing/pinning. The high risk accords with the results after closed reduction and hip spica (Jerre 1950, Ordeberg et al. 1986a). Most of the reduced hips were still considerably displaced and showed low ATD values, indicating residual and severe displacement and/or growth disturbance.

Follow-up. Most patients had a normal range of motion and walked long distances without walking aids. Some had pain due to pin protrusion or metallic corrosion, which disappeared after nail/pin extraction.

The preponderance of severe slippings during the earlier years (Figure 21) and among nailed hips (Figure 20) could be accounted for the longer delay between onset of slipping and diagnosis during the earlier years (Hägglund et al. 1984). Further, during the 1950s and early 1960s, when pinning was mostly used, some hips with severe slipping were treated by femoral neck osteotomy.

No grade 3 arthrosis was seen among patients with mild or moderate slipping at follow-up, whereas among 83 patients with severe slipping, there were 13 with grade 3 arthrosis. Arthrosis was about twice as frequent after reduction than after fixation in situ. Regarding grade 3 arthrosis only, the difference was 13 to 1.

In summary, the only early complication associated with arthrosis was segmental collapse. This complication occurred in 4/25 hips operated on with reduction and in 4/179 hips operated on with fixation in situ. Arthrosis increased with the degree of slipping and was more frequent after reduction than after fixation in situ. Arthrosis did not increase with follow-up time among those nailed or pinned without reduction.

2. Femoral neck osteotomy

In all 33 patients (hips) the preoperative displacement was reported as severe. The operative technique and the postoperative management have been described in detail by Wiberg (1966).

Early complications. Eight hips developed segmental collapse, and three hips showed chondrolysis. One male with postoperative infection also had segmental collapse and chondrolysis, which could be a result of a septic arthritis. These 10 cases were treated with non-weight bearing from 6 months up to 3 years. Of those patients with less than 3 months between onset of symptoms and osteotomy, 6/13 developed segmental collapse or chondrolysis, whereas of those with a history exceeding 3 months, 4/20 had these complications (Figure 23).

A postoperative wound infection was noticed in 3 cases. In one, antibiotic treatment was sufficient for healing, whereas in the other 2, operative drainage was needed. One male fell with his crutches during the period of non weight-bearing and sustained a supracondylar femoral fracture on the operated side. One male fell from his bicycle 8 months after osteotomy and sustained a breakage of the screw and a displacement of the osteotomy. He was operated on with extraction of the screw, reduction, and internal fixation with a bone peg.

Follow-up. Of the primary sample of 33 patients, 32 were reviewed by questionnaire, 28 by radiographic examination, and 26 by clinical examination (Table 17).

Table 17. Number of patients operated on by femoral neck osteotomy

Primary material	33
Dead at follow-up	1
Questionnaire	32
Clinically reexamined	26
Radiographically reexamined	28

One male and one female, both with segmental collapse, were operated on with total hip replacement because of severe arthrosis 22 and 23 years after the osteotomy. Another male with severe arthrosis was operated on with resurfacing hip arthroplasty 27 years after the osteotomy. One male, with chondrolysis, developed a shortening of 5 cm on the osteotomized side according to the clinical report. He was operated on with shortening osteotomy on the contralateral femur 5 years after the first operation. Twenty-three years after the femoral neck osteotomy, he was operated on again in the same hip because of arthrosis, now with McMurray osteotomy. In these 4 cases, radiographs and hip function before secondary operation were used for evaluation.

Nineteen patients had pain from their osteotomized hip and no one had a normal range of motion (Table 18). However, 23 patients could walk long distances without walking aids. The osteotomized leg was on an average 1.9 cm shorter (range 0-6 cm) than the contralateral leg.

Eighteen of the 28 osteotomized hips had arthrosis (Table 19). All nine hips with segmental collapse/chondrolysis had severe arthrosis. Of the contralateral hips, 11 evidenced slipping and one had mild arthrosis. Only three of these contralateral slippings were diagnosed during adolescence.

The articulo-trochanteric distance was almost the same as in those hips with severe slipping left without treatment, and did not differ from other methods of treatment (Table 16).

COMMENTS During adolescence the bony epiphysis of the proximal femur receives its main blood supply from arteries in the capsula reflexa (Trueta

Table 18. Function 28 (16-32) years after femoral neck osteotomy.
Cases with segmental collapse/chondrolysis in brackets

Grade	1	2	3	4	5	6	Total
Pain	4(2)	6(4)	4(1)	4(2)	1	13(1)	32
Motion	2(2)	2(2)	7(3)	9(1)	6		26
Walking		1(1)	3(3)	5(3)	11(3)	12	32

1957, Hulth 1958). It is obvious that subperiosteal dissection, traction, or excessive rotation of the epiphysis during surgery is hazardous to these vessels. All operations in our material have, however, been performed by experienced surgeons, with a technique designed to spare the vascular supply.

Segmental collapse or chondrolysis occurred in 10 of 33 hips. This frequency accords with most earlier reports concerning treatment of PCF with femoral neck osteotomy (Wilson et al. 1965, Dunn 1975, Gage et al. 1978). Identification of segmental collapse and chondrolysis were based on our own examination of postoperative radiographs or, when these were not available, of the original report of the radiologist. Only cases with a joint space reduction to less than 1/2 of that of the contralateral hip were classified as chondrolysis. Thus, the presented results should be regarded as minimum values.

Table 19. Slipping and arthrosis 28 (16-32) years after femoral neck osteotomy. In brackets, cases with segmental collapse or chondrolysis

		Slipping				Arthrosis			
		0	1	2	3	0	1	2	3
Osteotomized hip	Males				18(7)	7	3		8(7)
	Females				10(2)	3	3	1	3(2)
Contralateral hip	Males	10	4	1	3	17	1		
	Females	7	2	1		10			

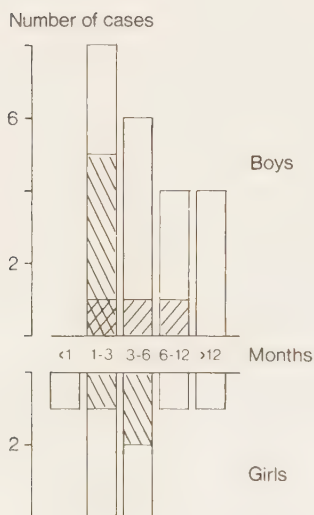


Figure 23. Number of patients in relation to sex and time between slipping and femoral neck osteotomy. \\\ = patients with segmental collapse; /// = patients with chondrolysis; □ = no complication.

There were more cases with segmental collapse among those with short delay between onset of symptoms and slipping (Figure 23). Dunn (1975) presented less satisfactory results in cases with an acute on chronic slipping compared with chronic slipping. These differences may be explained by a better vascular adaptation in cases with a chronic and slow slipping. In acute slippings there is probably also an instability in the physis during osteotomy, increasing the risk of peroperative damage of the retinacular vessels. Most slipped epiphyses have a normal vitality preoperatively (Hägglund et al. 1985), and segmental collapse should in most cases be regarded as a complication of the treatment and not of the slipping.

Chondrolysis was first described in 1930 by Waldenström. He realized that the joint cartilage receives its nourishment from the synovial fluid and that chondrolysis must result from some impairment of this nutrition. Cruess (1963) found at histologic examinations, besides destruction of the joint cartilage, an almost complete destruction of the synovial lining, and supported the theory of Waldenström. Because the hip joint is a ball-and-socket joint, the pumping function during motion is important for the nutrition of the cartilage, and Cruess supposed that chondrolysis

resulted from decreased production of synovial fluid in combination with surgical trauma and postoperative immobilization. Based on histologic and immunologic studies, Mankin et al. (1975) and Ingram et al. (1982) believed that chondrolysis is an immunologic response to cartilage antigens.

The ATD was almost the same as in the untreated hips with severe slipping (Table 16). Because the deformity was surgically corrected in the osteotomized hips, this operation probably resulted in a varying growth disturbance due to the physiodesis after screw fixation or to avascular necrosis.

In summary, one third of the hips with PCF treated by wedge osteotomy of the femoral neck were complicated by segmental collapse or chondrolysis, and severe arthrosis developed early in these hips. The remaining two thirds, in general, had no or only mild arthrosis and satisfactory function 30 years after the osteotomy.

V General discussion and conclusions

A. EPIDEMIOLOGY AND ETIOLOGY

The epidemiologic and etiologic studies suggest that PCF has a multifactorial etiology. These studies can be summarized under mechanical, hormonal, and familial predisposing factors.

1. Mechanical

Only occasionally was the PCF due to a heavy trauma; trauma is of minor importance in most cases. Children with PCF are overweight (***) at time of slipping and remain overweight until maturity, resulting in a higher than average load on the growth plate. The growth-plate is weaker during periods of rapid growth (Morscher 1968). The slipping occurs mostly during the period of increasing height gain at puberty. The seasonal variation in incidence and the case (Chapter IVC) followed with RSA before, during, and after PCF suggests a temporarily increased growth rate before and at time of onset of slipping.

2. Hormonal

Animal experiments have shown that an imbalance between sex hormones and growth hormone (GH) weakens the growth plate (Harris 1950, Morscher 1968). In case reports, PCF has been associated with GH therapy (Fiddler & Brook 1974, Rennie & Mitchell 1974), hypothyroidism (Heyerman & Weiner 1984, Puri et al. 1985), and hypogonadism (Sørensen 1968, Primiano & Hughston 1971). The sex difference in incidence, the occurrence at puberty, and the decreasing age at onset parallel to the decreasing age at pubertal development indicate a connection with sexual hormones. The abnormal body constitution and the abnormal longitudinal

growth during puberty further suggest a disturbed hormonal regulation of growth as an etiologic factor of PCF.

3. Familial

Radiographic examination revealed PCF in about 10 per cent of the first-degree relatives; one third of the families had more than one member with PCF. In 3/164 first-degree relatives, PCF was diagnosed during adolescence, which is higher (***) than expected from the incidence investigation.

However, there are still some findings that are not explained by these etiologic factors. The rural/urban differences in incidence and the periodic incidence pattern remain obscure. Perhaps nutritional or other environmental factors with the same periodicity and geographic difference affect those who are at risk of contracting PCF. However, to date no evidence has been presented.

B. THERAPY

Long-term follow-up investigations have been presented earlier from the same region after no primary treatment (Ordeberg et al. 1984) and closed reduction and hip spica (Ordeberg et al. 1986a).

The high risk (1/3) of osteonecrosis or chondrolysis after femoral neck osteotomy gives an overall poor long-term result. In fact, the frequency of arthrosis at follow-up was similar to frequencies of arthrosis with severe slipping left without primary treatment, though the latter were reexamined on an average 9 years later (Table 20). In intertrochanteric or subtrochanteric osteotomy, the risk of segmental collapse seems to be reduced (Southwick 1973), whereas the risk of chondrolysis seems to be increased (Frymoyer 1974).

The long-term results after nailing/pinning without reduction was superior to osteotomy or nonoperative treatment, regardless of degree of slipping. Those nailed/pinned with reduction before 1950 have a poor

Table 20. Arthrosis at follow-up related to method of treatment in hips with severe slipping. No treatment according to Ordeberg et al. 1984

Method	Arthrosis				Total no. of hips
	0	1	2	3	
Nailing in situ	28	13	0	3	44
Nailing, reduction	0	1	0	7	8
Pinning in situ	17	9	0	2	28
Pinning, reduction	3	0	0	0	3
Femoral neck osteotomy	10	6	1	11	28
No treatment	7	10	6	12	35

function and a high frequency of severe arthrosis. Jerre (1950) warned for reduction of chronic slippings. Maybe, those treated with reduction during the 1950s and 1960s had mostly an acute or acute-on-chronic slipping, which would account for the better results in these patients. However, there were no patients with mild or moderate slipping treated with in situ nailing/pinning with severe arthrosis at follow-up. Consequently, there is no reason to actively reduce mild or moderate slippings. The high frequency of lost epiphyseal grip due to sliding or growth, with the risk of reslipping, is avoided using the hook-pin with reliable anchorage in the epiphysis.

Some authors (Herndon et al. 1963, De Palma 1964, Howorth 1966) prefer bone pegging through the growth plate of the femoral neck to secure physiodesis. This method has shown good short-term results, similar to nailing/pinning. However, the operative procedure is more complicated and the patients are not allowed full weight-bearing postoperatively. The physiodesis may result in leg-length discrepancy and limited range of abduction owing to continuous growth of the trochanter major (Howorth 1966), which is important in cases with early and unilateral slipping. The use of screws to obtain growth plate closure results in the same problems with leg-length discrepancy and reduced

abduction besides the problems at insertion and extraction (Cameron et al. 1978, Friberg et al. 1984), which can be avoided by using the hook-pin (Hansson 1982, Hansson et al. 1986).

Bilateral PCF has been diagnosed in 20-25 per cent of this patient group during adolescence in most investigations (Burrows 1957, Wilson et al. 1965, Sørensen 1968), as in our material (24 per cent). Using more careful radiographic analysis, Klein et al. (1953) reported 41 per cent, Jerre (1950) 42 per cent, and Billing & Severin (1959) 80 per cent bilateral slipping. At radiographic follow-up, using the relation between the femoral head and calcar femorale, bilateral slipping was seen in 62 per cent in our material. The high frequency of bilateral slipping and the corresponding increased risk of contracting arthrosis have changed our policy. All cases with PCF are nowadays treated by prophylactic pinning of the contralateral hip, even if this side is asymptomatic and radiographically normal (Hansson 1982).

In conclusion, the long-term results after PCF mainly depend on the severity of slipping and the method of treatment. If technically possible, pinning in situ seems to be the method of choice regardless of degree of slipping. Closed reduction under anesthesia, after preoperative pin traction with flexion, inward rotation and abduction, should only be tried in acute severe slippings. Many early complications are prevented using pins with satisfactory anchorage in the epiphysis. Prophylactic pinning of the contralateral hip is recommended, but it must be performed with an atraumatic technique not affecting the development of the hip.

VI General summary

This thesis is based on 532 cases of physiolysis colli femoris (PCF) in southern Sweden from 1910 through 1982. The material was analyzed epidemiologically. Subsets were used for different investigations aimed at surveying the etiology of PCF, and long-term follow-ups were conducted after operative treatment.

After radiographic examination of anatomic specimens and normal hips, a method to diagnose and grade PCF was developed. The calcar femorale was found to be of constant shape and position and was used as a landmark to which the position of the femoral head was related. The advantage of this method is that it is easy to use and it is able to determine PCF also after growth-plate closure.

Epidemiologic analysis of the total material revealed large changes during the 20th century. The disease is more common in males than in females, but the male predominance has decreased from about 90 per cent to about 60 per cent during the period of investigation. Mean age at onset of slipping has decreased by about 3 years in males to 12.7 years and by about 1 year in females to 11.8 years. The incidence has followed a periodic pattern with peaks approximately every 20th year. The mean incidence was 6/10,000 in boys and 3/10,000 in girls. Boys living in the country have always been at higher risk than those living in cities. They were also at higher risk of sustaining bilateral slipping. In girls there is a seasonal variation, with a higher incidence between May and August.

The etiologic investigations dealt with hereditary, mechanical, and hormonal aspects. Radiographic examination revealed PCF in about 10 per cent of the first-degree relatives of 50 consecutive patients with PCF. One third of the families had two or more members with PCF. This familial accumulation is much higher than shown in earlier investigations based on questionnaires or clinical reports, and higher (***) than expected from the incidence calculations.

The growth analysis using the ICP model showed in both sexes an above average body height before puberty. However, at maturity the heights were almost normal, and accordingly the pubertal gain in height was lower than normal. Both the boys and the girls were markedly overweight before puberty and remained so at maturity. The ICP model accords with what is known about hormonal regulation of growth, and the growth abnormalities indicate a disturbed hormonal growth regulation. Most patients had their onset of symptoms during the period of increasing growth at puberty.

RSA of longitudinal growth in the distal fibula showed in both sexes an almost normal rate during the years after pinning of the PCF. However, at diagnosis 13 children (17 when adjusted for skeletal age) of the 32 investigated had a body height exceeding the mean value by more than 1 SD, indicating higher than average growth before diagnosis. This is supported by the result from one boy with growth measurements also before slipping, showing a temporarily marked increased growth rate at time of onset of symptoms probably resulting in a weaker growth plate.

In the investigations concerning therapy, 33 cases treated with femoral neck osteotomy and 172 cases treated with Johansson nailing or Nyström pinning were evaluated on an average 28 (16-42) years after surgery.

Of the osteotomized patients, 10 out of 33 sustained segmental collapse and/or chondrolysis. These patients developed severe arthrosis at an early age and had poor function at follow-up. The remaining 2/3 had satisfactory function and, in general, no or only mild arthrosis.

Of the nailed/pinned cases, four of 25 hips treated with reduction and four of 179 hips operated on without reduction developed segmental collapse. This complication was associated with poor long-term results. There was a high frequency of lost epiphyseal grip due to sliding of the nail/pin or growth in length of the femoral neck resulting in many reoperations. No increase in arthrosis was found associated with this complication. Arthrosis was twice as frequent at follow-up after reduction (1/2) than after fixation in situ (1/4). Regarding severe arthrosis only, the ratio was 13 to 1. No severe arthrosis was seen after mild or moderate PCF that was nailed or pinned without reduction. The clinical and radiographic results were better than those from the same region after femoral neck osteotomy or nonoperative treatment. It is concluded that pinning in situ is the method of choice regardless of degree of slipping. Bilateral slipping was found in 62 per cent of the patients at follow-up, indicating prophylactic pinning of the contralateral hip in cases with unilateral slipping.

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